

# Design and analysis of frequency reconfigurable antenna in S-band

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## ABSTRACT

One of the biggest challenges in modern communication systems is to provide a single antenna for multiple applications. Existing antenna systems are limited to some applications. Therefore, it is important to design a single reconfigurable antenna for multiple applications in current communication systems. To overcome this problem, a single antenna with frequency reconfiguration capability has been developed in this work. In this work, four different frequency reconfigurable antenna layouts are investigated. To provide frequency reconfigurability, the proposed antenna comprises two P-intrinsic-N (PIN) diodes placed between the microstrip line and patch. The antenna can resonate in four states and operate at three distinct frequencies without affecting the size of the antenna by toggling the 'ON' and 'OFF' modes of the PIN diodes. The antenna can operate at three different frequency ranges, depending on the switching state of the PIN diode 2.1, 2.4 and 3.0 GHz. The voltage standing wave ratio (VSWR), gain, return loss (RL) and radiation patterns of the antennas were simulated and measured. It is clear that the proposed antenna works at different operating frequencies. The gain and RL for the corresponding frequencies are significantly improved and the radiation pattern is symmetrical.

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## 1. INTRODUCTION

Many researchers are interested in reconfigurable antennas [1], [2] because they include polarization, frequency, and radiation pattern reconfigurability and act as transmitters and receivers of antennas in wireless communication systems [3]–[5]. By changing the antenna design, we can change the antenna parameters such as polarization, frequency, or radiation pattern using varactor diodes, radio frequency (RF) P-intrinsic-N (PIN) diodes, and RF microelectromechanical system (RF MEMS) switches can all be used to achieve reconfigurability [6]–[8]. The switching of a PIN diode is 500-1,000 times faster than that of RF-MEMS, and PIN diodes are smaller and have dynamic reconfiguration. Reconfigurable antennas have unique characteristics such as minimum size, uniform radiation beam across all working frequency bands, reduced spurious signals, and co-site interference [9]–[13]. The resonant frequency of a reconfigurable antenna is changed according to the desired use. Controlling the effective length of the antenna dimensions allows the frequency to be reconfigured. The effective length of the structure has a significant impact on the antennas operating frequencies of the antennas [14]–[17].

This paper is about a frequency reconfigurable antenna with two switches that can be switched for four different frequency ranges. This antenna consists of a rectangular patch with two PIN diodes. For resonance on several frequency bands, RF PIN diodes are used. The main advantage of the proposed

reconfigurable antenna is that it can resonate at three different frequencies. Instead of using two or three antennas, a single antenna is used that radiates at three different frequencies. Tunable antennas (also called reconfigurable antennas) are divided into several types: continuous and switching [18]–[21]. Continuous frequency tunable antennas allow seamless changes within or between operating ranges. Switched tunable antennas, on the other hand, operate in different and separate frequency bands [22], [23] using some type of switching mechanism. The key differentiators are the magnitude of the changes in effective length that allow operation across multiple frequency bands and the methods used to produce these changes.

## 2. ANTENNA DESIGN

The designed frequency reconfigurable microstrip patch antenna was operated in S-band. The antenna was built or fabricated on an FR4 substrate with the dimensions. The FR4 substrate with its high dielectric constant is ideal for reducing the size of the antenna. The length and width of the patch are  $L=40$  mm and  $W=46.4$  mm, which were calculated using the equations. The dimensions of the patch for frequency reconfigurability are changed and optimized during simulation using ANSYS high frequency structure simulator (HFSS). An offset cut of  $11 \times 22.3$  mm is made on the patch for impedance matching. A  $5 \times 48$  mm microstrip line is inserted into the patch; however, there is no connection between the patch and the strip, so this method of feeding is called proximity feeding. Two PIN diodes are connected to both sides of the microstrip line, and power is transferred from the microstrip line to the microstrip patch using these diodes.

The designed antenna is fabricated on an FR4 substrate with a thickness of 1.6 mm, a dielectric constant of 4.4, and a loss tangent of 0.02. The antenna is fed with a  $50 \Omega$  microstrip line. The FR4 substrate is used to reduce the size of the antenna due to its high dielectric constant. Mostly PIN diodes are used because they're fast switching, compact and reliable. By switching the "ON" and "OFF" of two PIN diodes (corresponding to four states, namely S0, S1, S2, and S3), the antenna can operate at 2.1, 2.4, and 3.0 GHz, respectively. The PIN diode equivalent circuit for two states is shown in Figure 1. The frequency response of an antenna is defined as its input impedance versus frequency. From Figure 1, the input impedance of the PIN diode in the OFF state is equal to  $Z_{in}=XC//R+XL$  and the input impedance of the PIN diode in the ON state is equal to  $Z_{in}=XL+R$ .

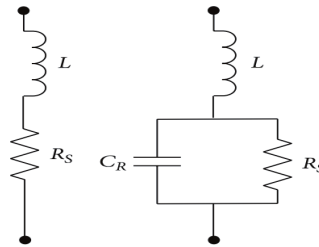


Figure 1. Equivalent PIN diode circuits for ON and OFF state

The physical size of the antenna can be calculated using the following equations. The patch width is  $W$  and the effective length of the patch antenna  $L$  depends on the resonance frequency ( $f_0$ ) and is given by:

$$W = \frac{C}{2f_0\sqrt{\epsilon_r+1/2}} \quad (1)$$

$$L_{eff} = \frac{C}{2f_0\sqrt{\epsilon_{eff}}} \quad (2)$$

Effective dielectric constant is given by:

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2\sqrt{1+12\frac{h}{w}}} \quad (3)$$

$\frac{1}{\sqrt{\mu_0\epsilon_0}} = C$  here  $C$  is the velocity of light  $=3 \times 10^8$  m/s. Resonance frequency:

$$Fr \approx \frac{C}{2L\sqrt{\epsilon_r}} = \frac{1}{2L\sqrt{\epsilon_r\mu_0\epsilon_0}} \quad (4)$$

The return loss (RL) S11 is related as:

$$RL = -20 \log \frac{VSWR-1}{VSWR+1} = -20 \log |\Gamma| \quad (5)$$

$$VSWR = \frac{1 + 10^{\frac{-RL}{20}}}{1 - 10^{\frac{-RL}{20}}}$$

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (6)$$

Reflection coefficient:

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} = |\Gamma| = 10^{\frac{-RL}{20}} \quad (7)$$

Reflection coefficient in terms of impedance:

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \quad (8)$$

Input impedance is given by:

$$Z_{in} = 90 * \frac{\epsilon_r^2}{\epsilon_r - 1} \left(\frac{L}{W}\right)^2 \quad (9)$$

Output impedance is given by:

$$Z_o = \sqrt{50 * Z_{in}} \quad (10)$$

The antenna with reconfigurable frequency is designed using ANSYS HFSS and the entire antenna parameters are shown in the corresponding Figure 2. The RL curve is plotted for all possible switching characteristics of the PIN diodes in the same graph, namely the states S0, S1, S2, and S3. In Figure 3, curve m1 indicates the RL for state S0 and the antenna is operating at 2.12 GHz. Curve m<sup>2</sup> shows the RL for the state and the antenna operates for 2.4 GHz. Curve m<sup>3</sup> shows the RL for the S2 state and the antenna operates for 2.4 GHz. Curve m<sup>4</sup> shows the RL for the S3 state, and the antenna operates for 3 GHz. Balanced operation is achieved by the antenna for S1 and S2 states.

Figure 4 shows the 3D radiation patterns for states S0, S1, S2, and S3. Figure 5 shows the 3D radiation pattern for state S0. In this state, the antenna has a maximum peak gain of 6.4 dBi and a beamwidth of 83 degrees. Figure 6 shows the 3D radiation pattern for the S1 state. In this state, the antenna achieves a maximum peak gain of 5.8 dBi and a beamwidth of 66 degrees. Figure 7 shows the radiation pattern for the state S2. In this state, the antenna has provided a maximum peak gain of 5.8 dBi and a beamwidth of 66 degrees. Figure 8 shows the radiation pattern for the S3 state. In this state, the antenna achieves a maximum peak gain of 7.4 dBi and a beamwidth of 76 degrees. Figure 4 shows the 2D radiation pattern of the proposed patch antenna.

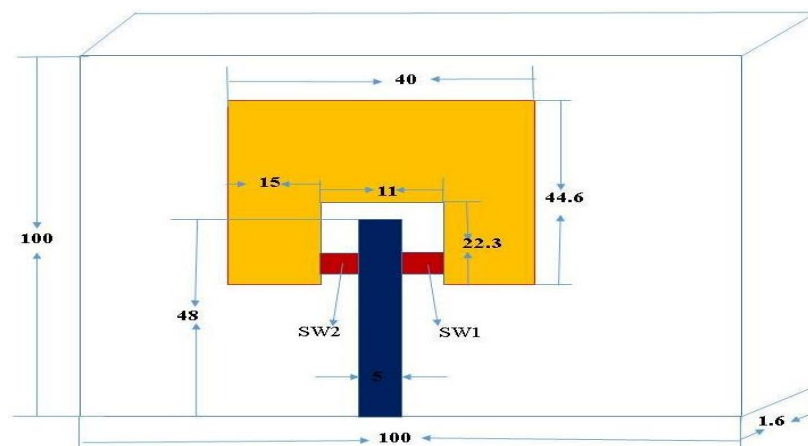


Figure 2. Proximity feed frequency reconfigurable antenna schematic

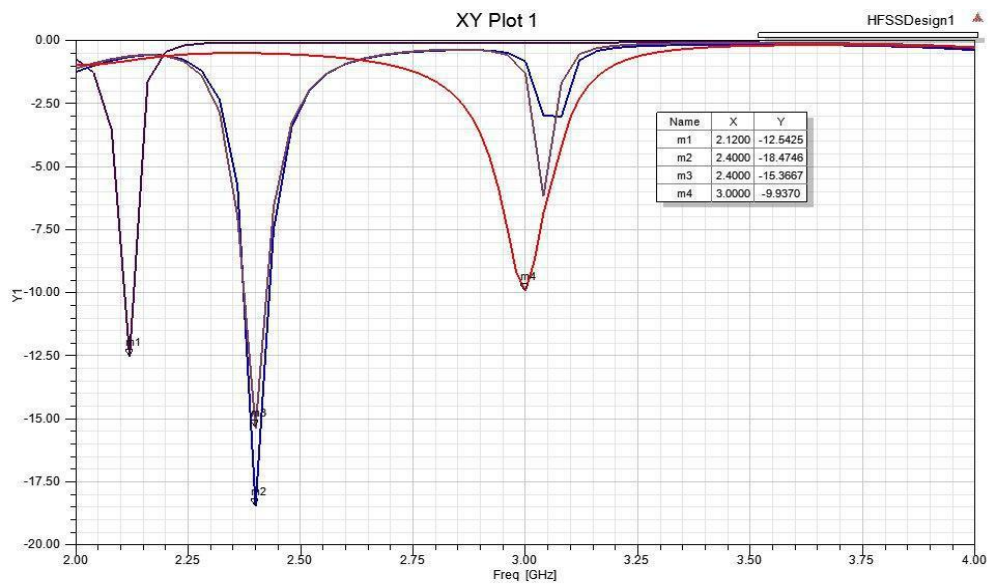


Figure 3. RL plot for different states

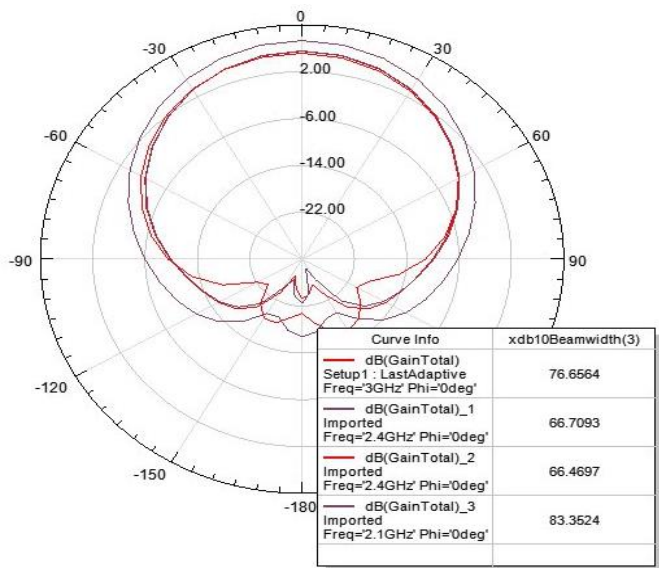


Figure 4. 2D-radiation pattern for all S0, S1, S2, and S3

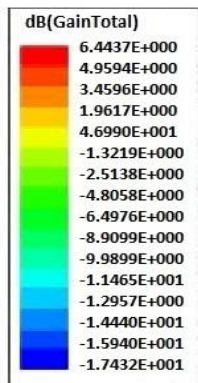


Figure 5. 3D-radiation patterns for state S0

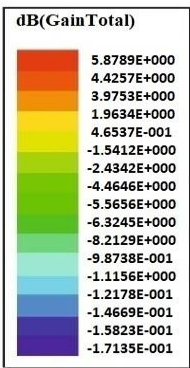


Figure 6. 3D-radiation patterns for state S1

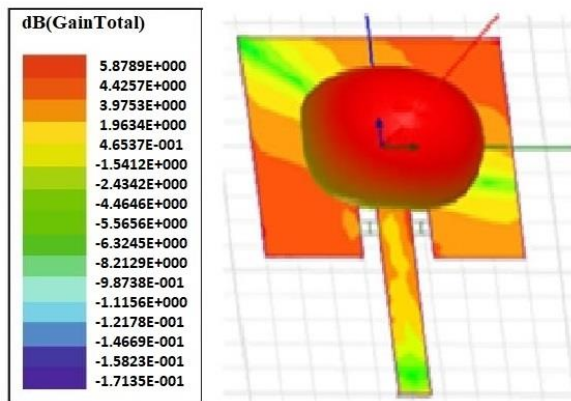


Figure 7. 3D-radiation patterns for state S2

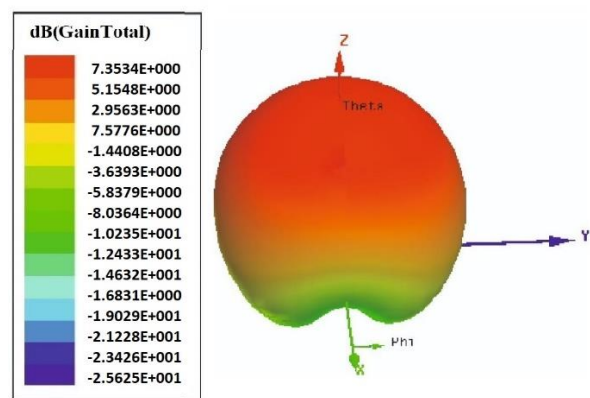


Figure 8. 3D-radiation patterns for state S3

### 3. RESULTS AND DISCUSSION

To validate the concept, a prototype frequency reconfigurable antenna was fabricated and tested. Figure 9 shows a picture of the fabricated antenna. The conditions ON and OFF are implemented by chip resistors with two different values. For the ON and OFF switching conditions, the values of the chip resistors are 0.001 and 3 k, respectively. Since the operating band and resonant frequencies are different for each of the four switching configurations, there is a slight shift in the operating band and resonant frequency due to the integration of the active components, and the measured reflection coefficient is between 2.1 and 3.0 GHz. The measured RL curve is shown in the same graph for all four switching states. PIN diodes are operated in 4 states and their conditions for 4 states are shown in Figure 10.

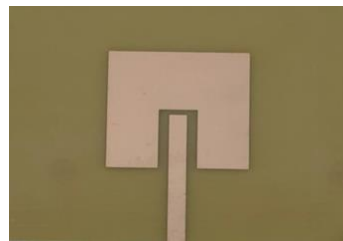


Figure 9. Fabricated prototype of frequency reconfigurable antenna

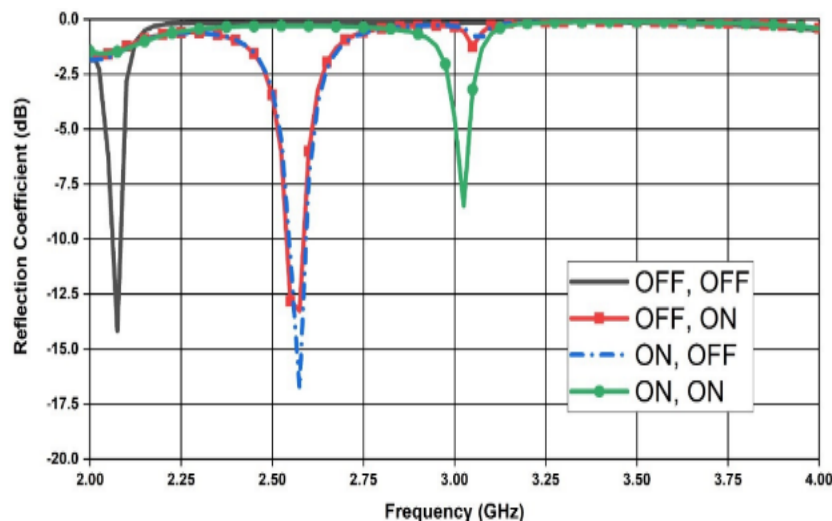


Figure 10. RL plot for different states of PIN diodes



Figure 11 shows the 2D radiation pattern of the reconfigurable antenna. Figure 12 shows the measured 3D radiation pattern for the S0 state. In this state, the antenna has a maximum gain of 5.5 dBi. Figure 13 shows the 3D radiation pattern for the S1 state. In this state, the antenna has the highest peak gain of 6.56 dBi. Figure 14 shows the 3D radiation pattern for the S2 state. In this condition, the antenna has the highest peak gain of 6.75 dBi. Figure 15 shows the 3D radiation pattern for state S3. In this state, the antenna reaches a maximum peak gain of 7.35 dBi.

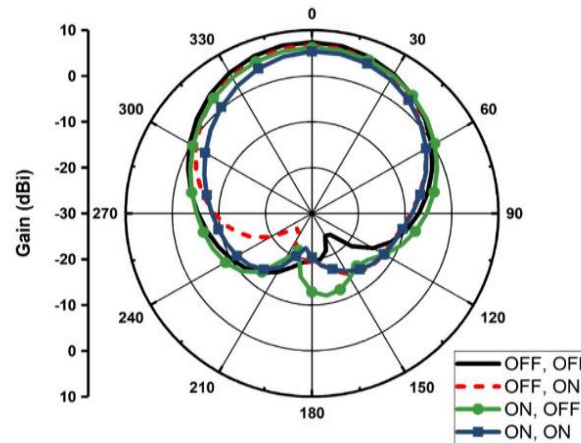


Figure 11. 2-D radiation pattern of frequency reconfigurable antenna

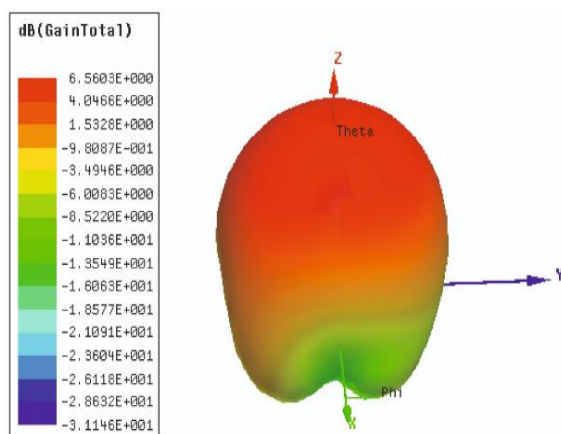


Figure 12. 3D-radiation patterns for state S0

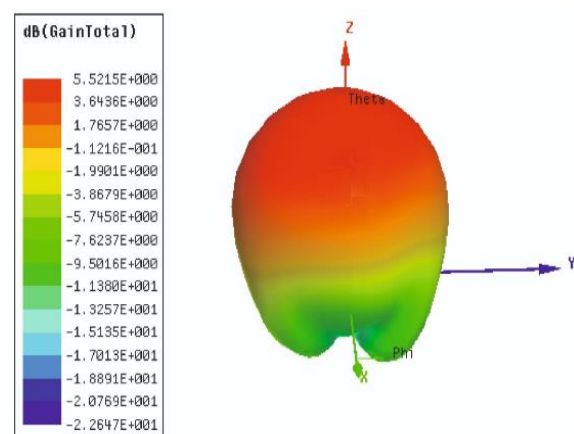


Figure 13. 3D-radiation pattern for state S1

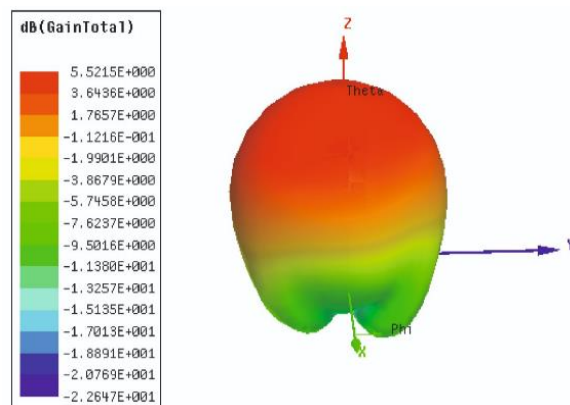


Figure 14. 3D-radiation pattern for state S2

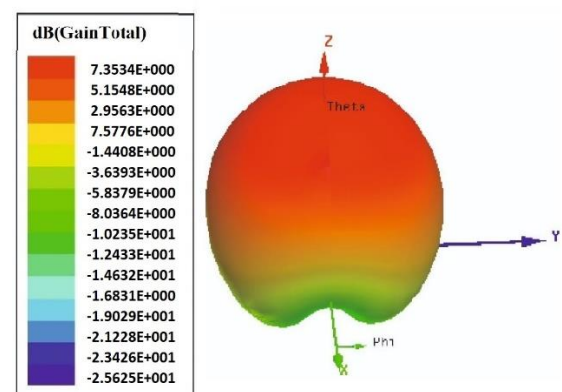


Figure 15. 3D-radiation patterns for state S3

Table 1 shows that a single antenna or a series of antennas in various arrangements, as a wideband antenna, as a multiband antenna, or in various forms of antennas [24], [25], have been proposed and developed by the respective authors for different frequency bands and different applications. Table 2 summarizes the RL and peak gains (simulated and measured) as a function of 2.1, 2.4, and 3.0 GHz frequencies for the designed antenna for all states (i.e., S0, S1, S2, and S3). From the table, it can be seen that the designed antenna (frequency configurable antenna) is best suited for the frequencies 2.1, 2.4, and 3.0 GHz.

Table 1. Comparison of proposed frequency reconfigurable antenna with other reference antennas

Ref	Antennas	Bandwidth	Applications
[26]	Single heart shape reconfigurable	2.12-2.88 GHz	Omnidirectional pattern
[27]	Frequency reconfigurable single port	2.0-2.8 GHz	WiMax/Cband, Cband/WLAN or Xband
[28]	Microstrip patch antenna	12.8-15.8 GHz	Ku band for satellite
[29]	Compact tuning fork shape ultra-wideband (UWB)	4.5-5.5 GHz	GPS, WLAN/Wi-Fi, WiMax, 4G LTE, UWB
[30]	Slotted bowtie antenna multiband and wideband antenna	3.5-9.0 GHz	Multimode communication systems
[31]	Planar inverted-F antenna	0.980-3.392 GHz	GPS, WLAN/Wi-Fi, WiMax, 4G LTE, UWB
[32]	Compact and multiband frequency	3.1-10.6 GHz	Cognitive radio
[33]	Hexagonal shaped microstrip UWB	3.1-10.6 GHz	Bluetooth and radar
[34]	Spiral labyrinth microstrip antenna	547-664 MHz	Digital television broadcasting
[35]	UWB antennas with band rejection	4.92-5.84 GHz	WiMax and WLAN band rejection
Proposed antenna	A single reconfigurable antenna for multiple applications	2.1, 2.4, and 3.0 GHz	Bluetooth, Wi-Fi, WiMAX, WLAN, GPS, military

Table 2. Summary of frequency reconfigurable antenna simulated and measured values

States	Resonating frequency (GHz)	RL (simulated) (dB)	RL (measured) (dB)	Peak gain (simulated) (dB)	Peak gain (measured) (dB)
S0 SW (1) OFF	2.1	-12	-13	6.4	6.56
SW (2) OFF					
S1 SW (1) ON	2.4	-18	-17.4	5.8	5.52
SW (2) OFF					
S2 SW (1) OFF	2.4	-15	-14.3	5.8	5.52
SW (2) ON					
S3 SW (1) ON	3	-10	-10.2	7.4	7.35
SW (2) ON					

#### 4. CONCLUSION

It can be seen that the proposed antenna works with different operating states of PIN diodes for three different frequencies such as 2.1, 2.4 and 3 GHz. The gain and return for the corresponding frequencies are satisfactory and the pattern is symmetrical for S1 and S2 states, which have the same resonant frequency and pattern. The beamwidth values were also observed during the simulation. The antenna can be used for three different applications including 3G communication, WLAN and weather radar by changing the operating conditions of the two PIN diodes.

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